GPPD Closed Cycle Refrigerator Experiment Procedure

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1 CCR Experiment Description

The GPPD maintains a dedicated closed cycle refrigerator (cryostat). The CCR is used for experiments when sample temperatures between 300 Kelvin and 10 Kelvin are desired. Temperature values in this range can be controlled within plus or minus one half a degree (usually better).

Note: This device is sometimes (incorrectly) referred to as a “Displex” which is a brand name used by a different manufacturer.

The samples are loaded into sealed vanadium cans; typically in a helium atmosphere. Helium is used for its thermal exchange properties and because of its gaseous state within the operating temperature range.

The CCR utilizes a cold finger to which the sample is mounted. The temperature of the cold finger is controlled by a heater mounted just above it. A thermometer diode is mounted to this cold finger and is the measure point for the temperature controller. After a specified equilibration delay, the cold finger temperature is assumed to be the same as the sample temperature. This value is monitored and used to effect data collection. Compared to a predefined value window, data collection continues as long as the temperature is within the window. A second diode is available but is not used in most GPPD CCR experiments.

Two heat shields, one inner and one outer, are employed to stabilize the sample temperature and to reduce or eliminate the temperature gradient across the sample.

The inner heat shield is controlled at the sample temperature. This ensures good performance at higher temperatures (closer to RT). It is made of aluminum with “aluminized” Mylar windows.

The outer heat shield is constantly at the displacement head’s second stage temperature of 50 Kelvin. This ensures good performance at the lower temperatures (closer to 10K). It is also made of aluminum with “aluminized” Mylar windows.

Note: Diffraction is <u>not</u> detectable from the window material.

The displacer head assembly, with sample and heat shields mounted, is placed in the GPPD’s sample well. The sample well is then evacuated to the low -5 to high -7 Torr pressure range (typical) using the GPPD sample well vacuum system. This eliminates air scattering and icing of the low temperature assemblies.

Neutron scattering occurs into all detectors. All available banks (and scattering angles) can be utilized. [Some pieces of sample environment (ancillary) equipment limit scattering angles, this does not.]

Figure 1 below the shows GPPD dedicated CCR device ready for deployment .

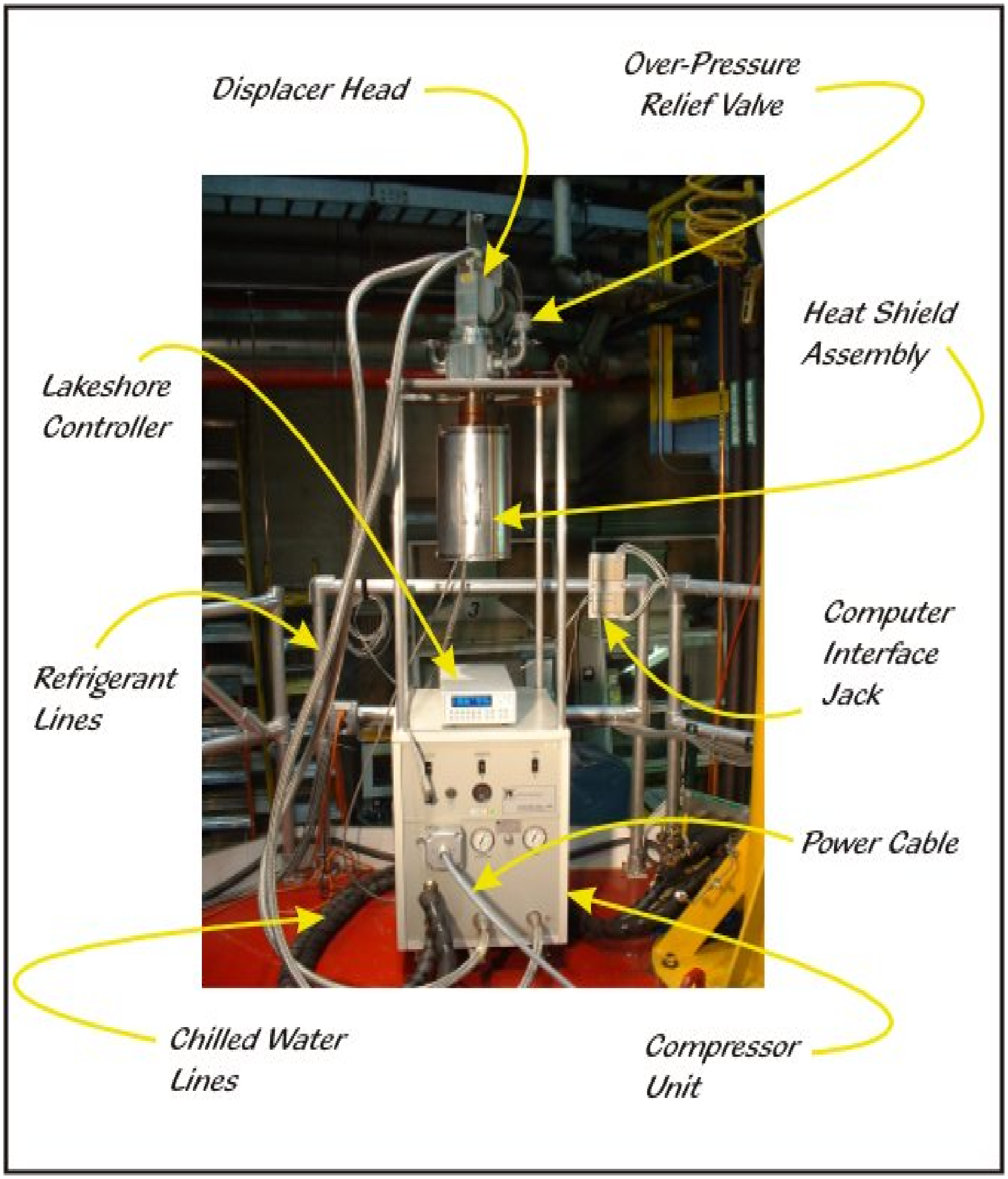

Figure 1: GPPD Dedicated CCR Device with major components identified.

GPPD personnel may perform some, most or all of the following procedures during the course of a user's experimentation time. The level of participation of the user may be determined by many factors including physical capabilities of the user and duration of the experiment. The user will be required to complete training activities in order to be designated access to this and other equipment. This documentation may be part of that training.

2 Starting the Experiment

Follow the procedures in the order presented.
For a quick reference, see Appendix A: Check List on page 21.

2.1 Set Up the LakeShore 332 Controller

1. Ensure that the LakeShore controller is plugged in and powered on.

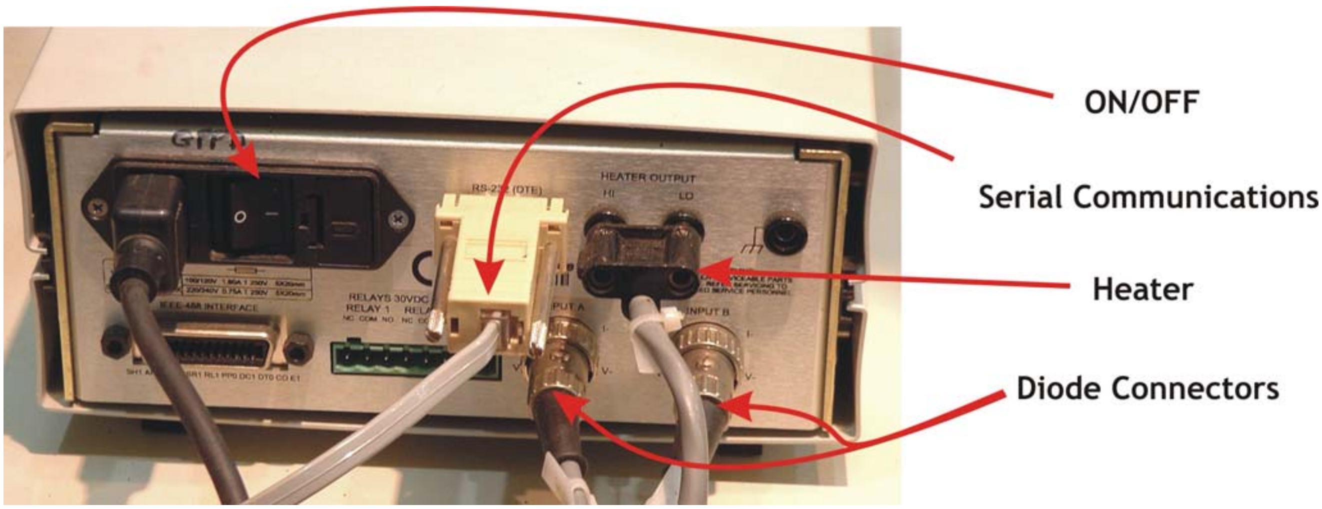

Figure 2: Rear of LS332

2. Make sure the heater is off or at 0% output power:
   a. Press the **Heater Off** button
   b. If it does not respond press the **Remote/Local** button and then press the **Heater Off** button again

   OR

   c. Make sure the set point is lower than the ambient (room) temperature see 3.1 Set Up the LS330 GUI Control Window on page 16.
3. Verify that the serial communications cable is plugged in at the adapter on the rear of the LS332 and at the Computer interface jack. See Figure 1 and Figure 2.

2.2 Identify the Temperature Sensing Diodes

There are two sensor diodes known as “A” and “B”. Typically the sensor at the cold finger is “A”. This identity is defined by connectors at the rear of the LakeShore 332 controller. The identity can be reversed by reversing these connections. To verify the diode identity:

1. Make sure the device is at or near room temperature.
   Caution: Never touch the extremely cold surfaces that may be present!
2. Using your index finger, gently touch the mounting screw of the diode on the “cold finger” shown in Figure 4.
3. Observe the LakeShore controller’s temperature display. An immediate rise in temperature will be seen on either the “A” or “B” temperature displays. This identifies the diode to be used for control and measure. Record the identity.

Figure 3: LakeShore controller showing A & B temperatures, set point value and heater power output.

2.3 Mount the Sample Can

The can mounts to the cold finger with a 5/40 stud.

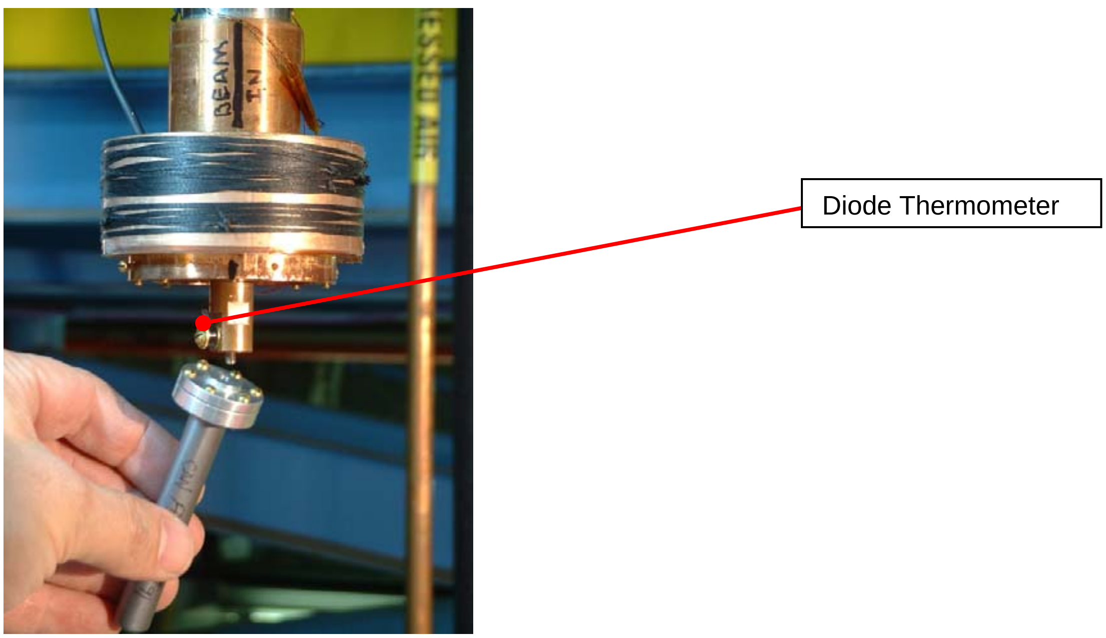

Figure 4 : Sample can being mounted to 5/40 stud.

1. Inspect the stud. It should appear clean but have a trace amount of thermal mounting grease. If the mounting position looks dirty, clean it with a “KimWipe”. (Alcohol can be used as needed.)

2. Re-apply a tiny amount of the Apiezon N (see Figure 5 below) to the mount area as needed. This special grease can be found in the small parts drawers in the GPPD sample prep area. If none is found, it is acceptable to mount the sample “dry”.

Figure 5: Thermal Mounting Grease

3. Carefully rotate the sample can onto the stud and gently "hand tighten" the sample can to the cold finger.

Caution: Tighten with extreme care!! Hold can by its aluminum flange to tighten.
- do not to over tighten or the stud will break off!
- avoid damaging the delicate wires of the diode thermometer (see Figure 4**)**

4. Turn the can no more that 1/8th turn after the flat surfaces of the can and cold finger meet. This equates to "hand tightened". There should be no visible gap between the cold finger and the top of the sample can. See Figure 6.


Figure 6: Mounted Sample Can

2.4 Install Heat Shields

2.4.1 Inner Heat Shield

The Inner Heat Shield mounts snugly to an aluminum flange near the bottom of the heater assembly. Once in place, it is secured by two small brass screws. The inner dimension of this heat shield closely matches the outer dimension of the mounting flange. This promotes a good thermal connection which is assisted by a small amount of Apiezon N.

Caption: Handle the Inner Heat Shield carefully:

- ***take care not to damage the aluminized Mylar***
- ***avoid damaging the delicate wires of the diode thermometer***

1. Inspect the flange and mounting surface of the shield. It should appear clean but have a trace amount of thermal mounting grease. If the mounting position looks dirty, clean it with a “KimWipe”. (Alcohol can be used as needed.)
2. Re-apply a tiny amount of the Apiezon N to the inner diameter of the heat shield near the mount area. This special grease can be found in the small parts drawers in the GPPD sample prep area. If it can’t be found, it is acceptable to mount the shield “dry”.
3. Locate the beam in markings on the cold head flange and alignment Align the screw slots in shield with brass screws on the mounting flange. See Figure 7.
4. Gently but firmly slide the shield onto the flange.
5. Ensure that the shield is on straight.
6. Secure the shield by gently tightening the small brass screws with a fine bladed screw driver.

   Note: The brass screws *always* remain on the flange. They only need a turn or two to loosen or tighten. This facilitates the installation and removal of this heat shield.

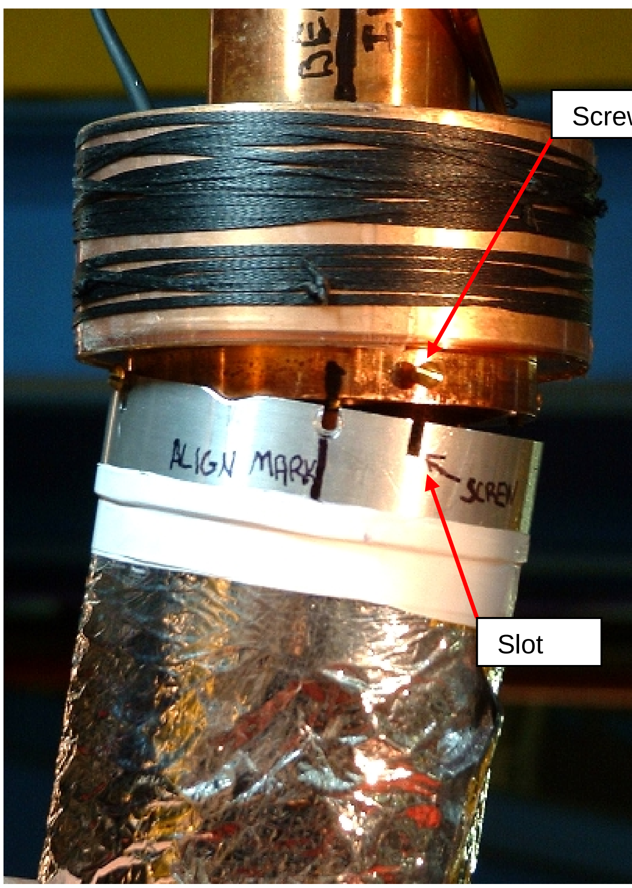

Figure 7: Align the screws and slots

Figure 8: Inner Heat Shield in place

2.4.2 Outer Heat Shield

The outer heat shield mounts to the wide flange above the heater and sample mount assembly. The shield is keyed for correct alignment and can only be mounted in one orientation.

1. Align the largest stud at the top of the outer heat shield with the largest hole in the flange. See Figure 9
2. Hold the shield up flush against the flange.

   NOTE: be careful to support the weight of the shield from the edges only! The bottom of the shield is thin metal and can be bent or broken.

3. Secure the flange using the knurled thumb nuts. See Figure 10

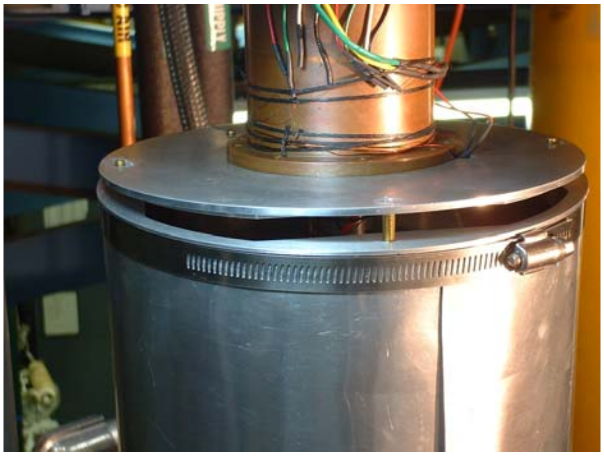

Figure 9: Aligning/mounting the outer heat shield.

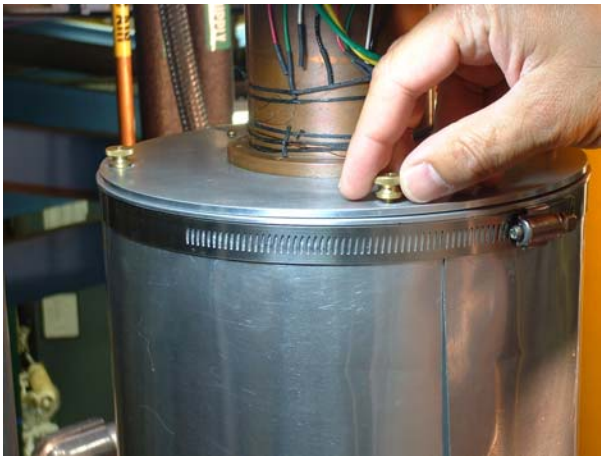

Figure 10: Secure with the knurled thumb nuts.

2.5 Select and Install Beam Mask

The boron nitride mask assembly is located in the beam entry port in the GPPD sample well. This mask assembly is only accessible from inside the sample well. This means that the mask size must be selected and adjusted before installing the CCR device in the well.

2.5.1 Mask removal:

1. Remove all devices from the GPPD sample well
2. Reach into the well and carefully remove the mask assembly by grasping the pull tab and pulling the assembly out about 5cm
3. Firmly grasp the body of this assembly and slide it out
4. Lift it out of the sample well

2.5.2 Mask Selection:

Either the 0.5” x 2.0” or the 0.375” x 1.5” main slit is recommended for most CCR experiments. Special applications will require installation of the secondary mask plates or selection of another main slit.

1. identify the mask currently installed
2. determine masking needed (see Appendix B: Mask Selection)
    a. eliminate scattering from top or bottom of can
    b. Beam center line is 1 - 11/16” below the sample mount
    12” below the main flange
    c. Total sample mass is centered in the beam.
3. Replace the main slit as needed.
4. Install secondary plates to adjust beam height dimensions as needed.

2.5.3 Mask installation:

1. Ensure that no devices are installed in the GPPD sample well.
2. Firmly grasp the body of this assembly.
3. Reach into the well and slide the mask assembly into the beam entry port. Slide it all the way in until it stops.

2.6 GPPD Re-Entrant Well Installation

1. Make sure sample well is empty.
2. Crane the re-entrant well into the sample well making sure to align the lock pin with the correct hole. See Figure 11, Figure 12, and Figure 13.

Warning: Use of the GPPD jib crane is only available to those who have received proper training! Limitations and requirements for using the crane will be fully explained during the crane training session. This instruction *does not* supplant crane training!

Figure 11: Removing Re-Entrant Well From Rack

Figure 12: Lift High Enough to Clear Stem

3. Remove the lock pin from the inner 12” flange (to facilitate installation of the CCR displacer head assembly) by unscrewing, place it nearby. Figure 14
4. Remove the inner 12” flange and move or remove the lifting harness. Figure 15


Figure 13: Align Pin of Large Flange


Figure 15: Straps are Clear / 12" Hole is Open


Figure 14: Removing Pin from 12" Flange


Figure 16: Prior to Lift, Stand to Left

2.7 Mounting the Displacer Head Assembly in the Sample Well

1. Connect the jib crane hook to the shackle at the top of the displacer head assy.

REMINDER - *before lifting:* center the swing arm and hoist directly above the hook point so the lift chain is vertical.

2. Organize the electrical control cables to prevent tangling.
3. Stand to the left side of the device. See Figure 16
4. Lift the displacer head about **3 inches (8 cm) only!** Figure 17
5. Pull the displacer head assembly towards you and out of the rack stand. Figure 18
6. Move the displacer head assembly towards the sample well slightly.
7. Begin lowering the displacer head assembly; you will notice that it twists appropriately towards the desired position.
8. As the heat shield assembly enters the well, use one hand on the compressor hoses to guide the device into the 12” hole. Figure 20
9. Once the device is in the hole, ensure a proper mating of the two flanges.

10. Carefully rotate the assembly to align the pin hole with the stamped "P". Figure 21
    Note: the device will rotate relatively easily once the flanges are correctly mated.
11. Re-install the lock pin and install the red locks. Figure 22: Locks Installed

Figure 17: Only Lift Three Inches (about)

Figure 18: Bring Toward You & Then Lower

Figure 19: Dress Refrigerant Lines Around the Well

Figure 20: Guide into Hole. Apply downwards pressure on pressure relief valve to level.

Figure 21: Manipulate to Mate Properly

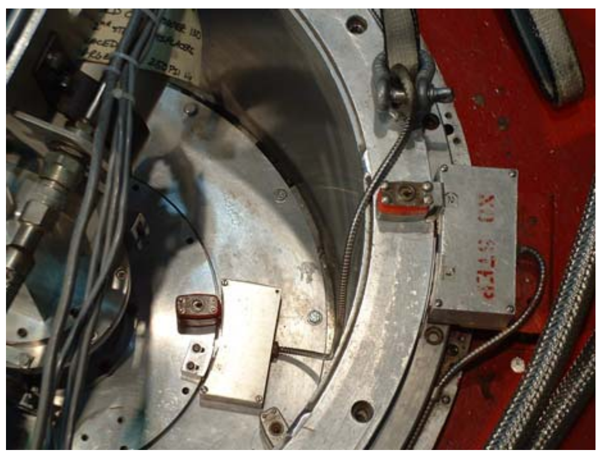

Figure 22: Locks Installed

2.8 Evacuate the Sample Chamber

At the GPPD sample well vacuum control panel:

1. Disengage the nitrogen back-fill by pulling outward on the vent switch, moving it to the right and then releasing it.
2. Ensure that System A is in Automatic by pulling outward on the switch, moving it to the left and then releasing it.
3. Engage the Automatic Enabled switch by pulling outward on the switch, moving it to the left and then releasing it.

You will hear the rough pump engage and start pumping. After about 5-10 minutes the vacuum level reaches “3.10e-2” [per readout] and the high-vac valve automatically opens to engage the cryo pump. This can be heard and is recognizable as a brief, loud “hiss”.

4. If not already done, open the EPICS (GUI) window on the professor computer by typing “`rdv`” or “`gp307`” at any command line.
5. Observe the vacuum levels. The display should show the numbers becoming more and more negative.
6. Once the high-vac valve is open, the CV gauge may display all zeros. Turn on the Ion Gauge to measure the vacuum when the cryo pump is engaged.
    a. Click on the IG1 button in the EPICS display. (the physical button on the Granville Phillips module can be pressed as an alternative method) ***Note: the IG will turn off automatically when the vacuum is poor.***
    b. Observe the display marked IG, the EPICS EG307 display only updates every 10 seconds so be patient.

2.9 Open the Beam Gate

Since the vacuum takes a few minutes to achieve the proper levels, it is good to get it started and then open the gate as the chamber is “pumping down”.

1. Verify that the vacuum is “pumping down” correctly.
2. Verify that the red locks are installed and the blue interlock light on the Beam Gate Control Panel is illuminated.
3. Insert the Beam Gate Key and turn it to the left or right until it “clicks”. Leave the key in place.
4. Press and hold the red OPEN button. The two red lights blink and the amber light illuminates. Hold the red OPEN button until the amber light goes off.

2.10 Turn On Chilled Water

The “Chilled Water” runs into the compressor unit to prevent it from overheating.

1. Locate the chilled water access to the left of the jib crane base.
2. Identify the lines that support the compressor.
3. Move the valve handles so that they are “in line” with (180 degrees to) the water lines
4. Make sure both Supply and Return are open. See Figure 23
5. Verify that the inlet hardware at the compressor feels cool to the touch.

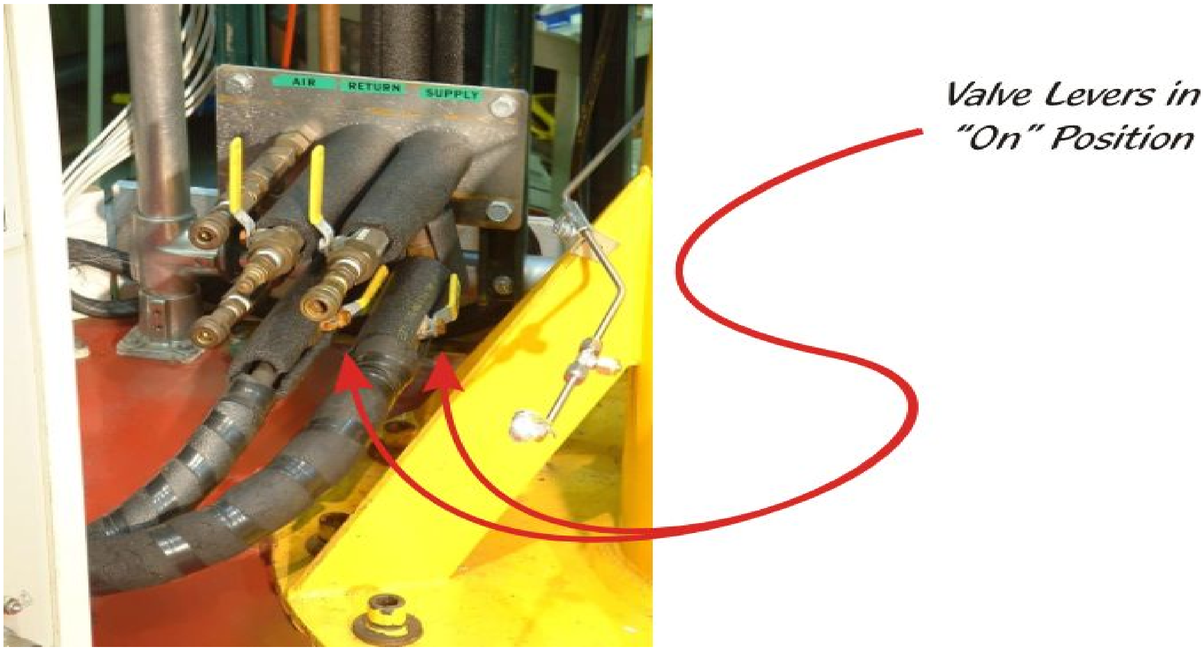

Figure 23: Chilled Water Access

2.11 Turn On Refrigeration

Temperatures from 300K down to 10K can be achieved with the compressor of the CCR operating. Best results occur when the core is fully cold so it is recommended to run the compressor for 30 min before beginning data collection. An alternative is to start at the 10K value (when appropriate). To do neither is also acceptable but the sample temperature may not be as stable until the core is fully cold.

1. Ensure coolant water is on. See: 2.10 Turn On Chilled Water above.
2. Plug in the power cable to the 480V / 3 phase jack on power panel.
   1) **Align the blades in the plug to the blades in the socket (notice keyed blade)**
   2) **Push in straight until the plug body is flush with the panel**
   3) **Turn plug body slightly to the right until it stops**
3. Move circuit breaker levers up in the following order (right to left)
   1) **Power On**
   2) **Compressor**
   3) **Cold Head**
4. Listen for the following:
   - The compressor will hum
   - After a delay, the cold head makes a pumping sound.
5. Observe temperature value on the LakeShore display. The temperature value should decrease if the heater is off or if the set point is below sample temperature. When the set point is at or above the sample temperature, the heater power can be observed attempting to maintain or increase the temperature. It may be desirable to do this deliberately in order to test the heater function.

Note: Never use a set point higher than 300K!

3 Prepare for Data Acquisition

3.1 Set Up the LS330 GUI Control Window

The Graphical User Interface (GUI) used here is labeled LakeShore 330. The device in use is a LS332 but it is running in a 330 simulation mode. This GUI works together with the Data Acquisition System (DAS), the values defined here must be selected so the DAS automation will work.

1. If not already done, type "`ls330`" at any command line on the professor computer.
2. The process opens with the "main" interface window. (See Figure 24 on page 17) If the window was open and a different display is seen, click on the **Main** button.
3. Locate the button labeled **Scan**. Click this button and it expands to display a selection of variables. Select **Enable All**.

Note: In the steps below: ensure that communication occurs between the GUI and the LS332 box on the compressor. Observe changes on both. If not, locate the button labeled **Scan**. Select **Disable All**, wait five seconds and select **Enable All** and try again.

4. Locate the button labeled **Control**. Click this button to switch to the "control" interface window. See: Figure 25
5. Observe the top left text display labeled **Sample.** There will be a text value shown in yellow of **Local** or in green of **Remote**. For this GUI and the DAS to work, the **Remote** mode must be active. Locate the button labeled **Mode**. Click this button and it expands to display a selection of variables. Select **Remote**.

   Note: If the display does not change, select **Local**, wait five seconds and select **Remote** again.

6. Observe the top left text display labeled **Sample.** There will be a text value shown in green of **Zone, Manual, P, PI or PID**. Locate the button labeled **Tune**. Click this button and it expands to display a selection of variables. Select **Zone**.
7. Locate the button labeled **Display**. Click this button to switch to the "display" interface window. See: Figure 26
8. Locate the buttons labeled **Sample** and **Control**. Select each to be the thermometer diode identified in step 2.2 Identify the Temperature Sensing Diodes on page 4.

Note: The **Lower Limit, Upper Limit,** and **Delay** values on the **Main** window affect data collection only and <u>do not</u> affect temperature control.

Note: Zone values in use are ones that have been pre-stored in the LakeShore controller! The Zone section of the GUI is not functional!

Note: All values not mentioned in this section should be previously set and should not be changed casually. If you are concerned or interested in changing anything else, contact GPPD instrument personnel before proceeding!

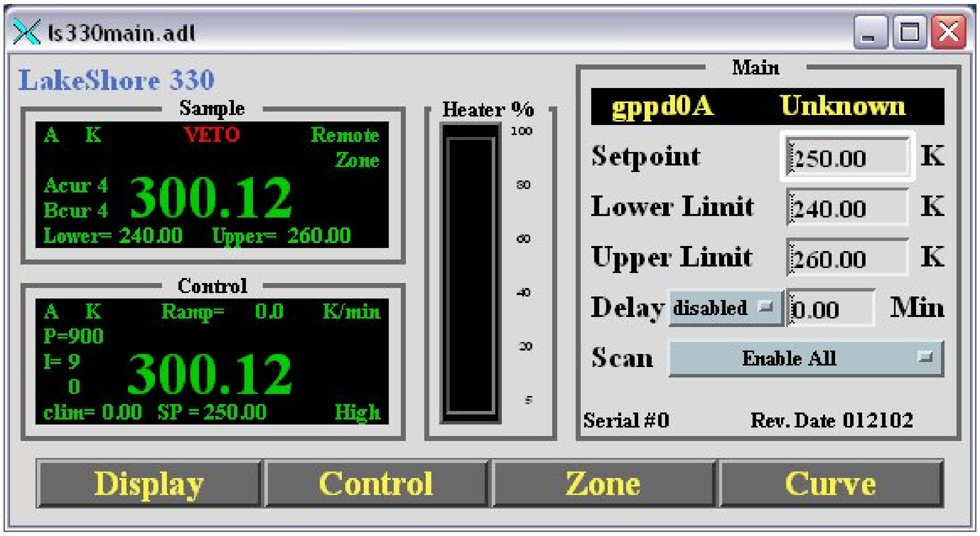

Figure 24: LS 330 Main Display

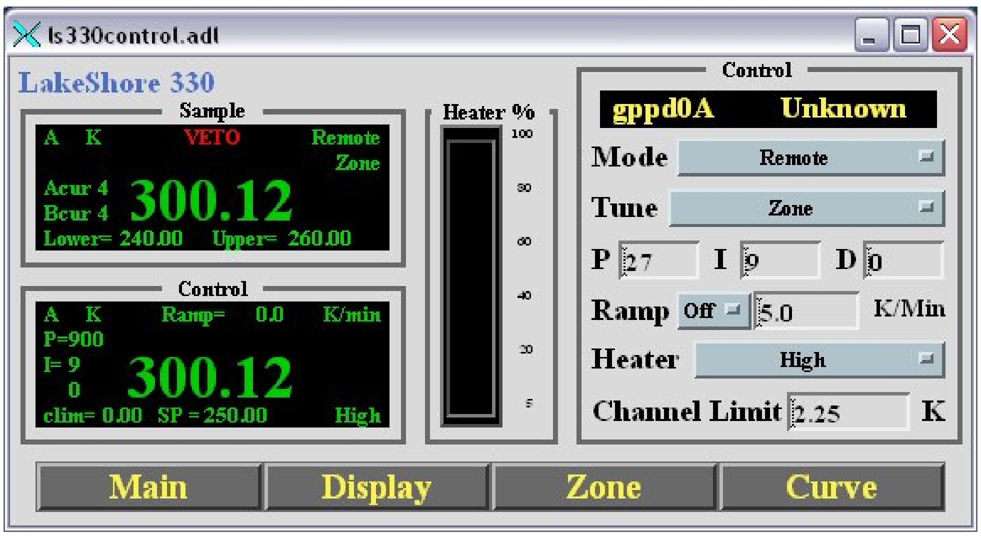

Figure 25: LS 330 "Control" Display

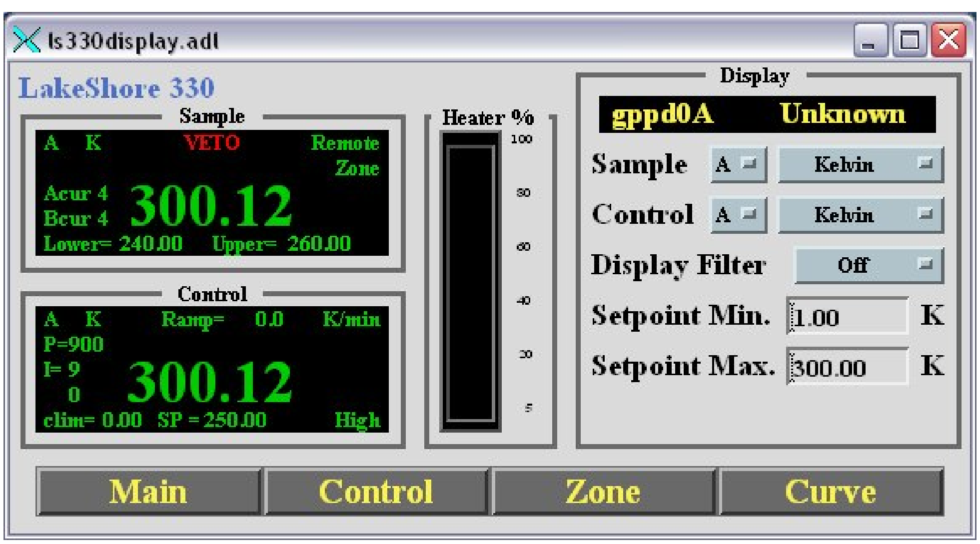

Figure 26: LS 330 "Display" Display

3.2 Design Experiment Details

3.2.1 Identify temperature scheme

Things to consider:

- Temperature values
- Warming – go immediately to the lowest temperature and then warm up, stopping at specified temperature values on the way up.
- Cooling - go immediately to the highest temperature and then cool down, stopping at specified temperature values on the way down.

3.2.2 Determine Time schedule

Things to consider:

- Scattering quality
    - o Previous neutron studies
    - o Material type
- Equilibration delays. See Appendix C: Temperature Response on page28
- Sample change opportunities
- Allotted experiment/beam time
- Scheduled Beam Outages ("Machine Research")
- Single run per data point (temperature)
- Multiple runs per data point (temperature)
  (studies of materials with unknown transitions may benefit from this approach)

3.2.3 Develop an Experiment Schedule

Lay out a rough experiment schedule. See Table 1 as an example.

Table 1: Simple Experiment Schedule

Sample	Temp	Start Time	Duration	Cycles	Pulses per Cycle
X-7	10K	10:00AM	2 hours	2	108000
X-7	50K	12:30 PM	2 hours	2	108000
X-7	100K	3:00PM	2 hours	2	108000
X-7	250K	5:30PM	2 hours	2	108000
change		7:30PM	1 hour		
X-11	10K	8:30 PM	2 hours	2	108000
X-11	50K	11:00 PM	2 hours	2	108000
X-11	100K	1:30 AM	2 hours	2	108000
X-11	250K	4:00 AM	2 hours	2	108000

3.3 Create a Control (CTL) file

The GPPD Instrument uses a special version of the Integrated Spectral Workbench (ISAW) program. The ISAW program is used to perform many tasks related to experimentation. One of those tasks is to generate run files. ISAW can use a special text file called a ***control file*** to generate run files with built-in control parameters and scheduling. This is very advantageous when automated data collection and multiple temperatures are desired. An example of a simple CTL file that can be used to create a set of runs for a CCR experiment is shown below:

```
2 RUNS
RUN 1 1 DEVICES
User "Kerry, Edwards"
Title "Zirconium Tungstate at 10.0"
type transmission
Schedule 10 108000
Displex.dat 3 PARAM
10.0  8.0  12.0
RUN 2 1 DEVICES
User "Kerry, Edwards"
Title "Zirconium Tungstate at 105.0"
type transmission
Schedule 10 108000
Displex.dat 3 PARAM
105.0  95.0  100.0
RUN 3 1 DEVICES
User "Kerry, Edwards"
Title "Zirconium Tungstate at 295.0"
type transmission
Schedule 3 108000
Displex.dat 3 PARAM
295.0  290.0  300.0
```

The most simplistic way of generating a CTL file is to copy a previously made file and modify it to fit your specific needs. If you look closely at this text, you will see where user names, run titles, data collection times, device type, target temperature and data collection window values are designated.

More information on CTL files can be found in the **GPPD Data Collection Handbook**.

3.4 Generate a Log File

A log file can be generated during the experiment by typing `CCRlog` at any command prompt on the “professor” computer. This will start a process that monitors and records time and temperature data every minute for four days.

More information on SDDS log files can be found in the **GPPD Data Collection Handbook**.

4 Data Collection

Data collection consists of generating run files manually or using CTL files to generate run files, starting a run sequence using the DAS GUI, monitoring the experiment’s progression, converting the raw data to usable “GSAS” (text format) files. Detailed information on this process can be found in the **GPPD Data Collection Handbook**.

5 Sample Changes

Sample changes require simple reversal of procedures mentioned previously plus two additional steps which are presented in detail below.
The outline of the sample change process is as follows:

1) Ensure data acquisition has stopped
2) Ensure that the temperature set point is below the actual temperature or turn the heater "off"
3) Turn off the refrigeration compressor, reversing the order (switches left to right) first Cold Head then Compressor then Power On (move levers down)
4) Vent the Sample chamber to atmosphere. See section 5.1 below.
5) Close the beam gate
6) Remove the red lock and the pin from the 12" flange
7) Crane the displacer head assembly out of the hole and place in rack
8) Warm the outer heat shield as necessary. See 5.2.1 Warming
9) Remove outer heat shield
10) Warm the inner heat shield as needed. See 5.2.1 Warming
11) Remove the inner heat shield and replace the sample can
12) Dry the device as needed. See 5.2.2 Drying
13) Reapply the steps of this procedure from sections 2-4 as needed

5.1 Venting the Sample Chamber

At the GPPD sample well vacuum control panel:

1. Disengage the Automatic Enabled switch by pulling outward on the switch, moving it to the right and then releasing it.
2. Engage the nitrogen back-fill by pulling outward on the vent switch, moving it to the left and then releasing it.

5.2 Warming and Drying the Device

5.2.1 Warming

The device will be very cold upon removal. During operation the outer heat shield is maintained at 50K and has no heater. This will cause rapid frosting of the device when exposed to the room air. The extreme cold will also make it difficult to remove the heat shields. One way to avoid this is to turn off the compressor and wait until the device has warmed. This usually takes at least a couple of hours and is therefore not practical. To decrease the time between data collection on samples, use a heat gun to blow hot air on the cold surfaces.
Caution: This must be done with great care to avoid damaging the delicate components. Always hold the heat gun at least 12" to 15" from the surface being heated. **Note: The heat gun warming process will take 10 minutes (or so). Do not rush this process!**

5.2.2 Drying

It is advisable to dry the device before returning it to the sample well. Effective drying can be achieved using the heat gun in the same manner as described above. Careful "blotting" of the wet surfaces with a large paper tissue is acceptable but avoid damaging the delicate parts such as diode wires.

6 Appendix A: Check List

- ❑ LakeShore controller is connected, plugged in and “powered on”.
- ❑ Temperature sensing diode identity is verified.
- ❑ Sample loaded in V can w/indium seal under helium atmosphere
  or in V can w/copper seal under helium atmosphere in glove bag.
- ❑ Sample mounted to CCR cold finger: a small amount of Apiezon N grease applied to enhance thermal conductivity and firmly but gently screwed in.
- ❑ Inner heat shield is in place and secured by firm but gentle tightening of the small brass screws.
- ❑ Outer heat shield is mounted and secured by four brass knurled nuts.
- ❑ Boron nitride [BN] mask is correctly selected and in place.
- ❑ GPPD re-entrant well is mounted in sample well and center flange removed.
  (temporarily remove pin from 12” flange to facilitate installation)
- ❑ Displex is placed in the re-entrant well and “P” is aligned to the pin.
- ❑ Sample chamber is evacuated to 5x10^-4 or better.
- ❑ Red locks in place, blue interlock light is illuminated and the beam gate is in the open position.
- ❑ Coolant water is flowing into the compressor.
- ❑ Compressor is plugged in to the 480 V / 3 phase electrical outlet.
- ❑ Compressor circuit breakers are switched on (right to left).
- ❑ Serial communications cable is connected at back of LakeShore and at jack plate.
- ❑ EPICS ls330 window is open:
  - **Scan**= Enable All
  - **Mode**= Remote [Under Control]
    - reads Remote “in green” on EPICS display GUI
    - blue “Remote” LED is lit on controller box
  - **Tune**= Zone
  - **Sample** and **Control =** both set to the previously identified diode
- ❑ Control file (CTL file) generated, run files generated, schedule verified and first run started.
- ❑ Log file is generated (`CCRlog` at any command prompt) (runs 4 days) (optional).

7 Appendix B: Mask Selection

The Following diagrams can be use to assist in determining a proper mask selection.

These diagrams are as accurate as possible but are simply a reference. It will pay to mask conservatively and perform a test scan for artifact scattering before starting a long run series.

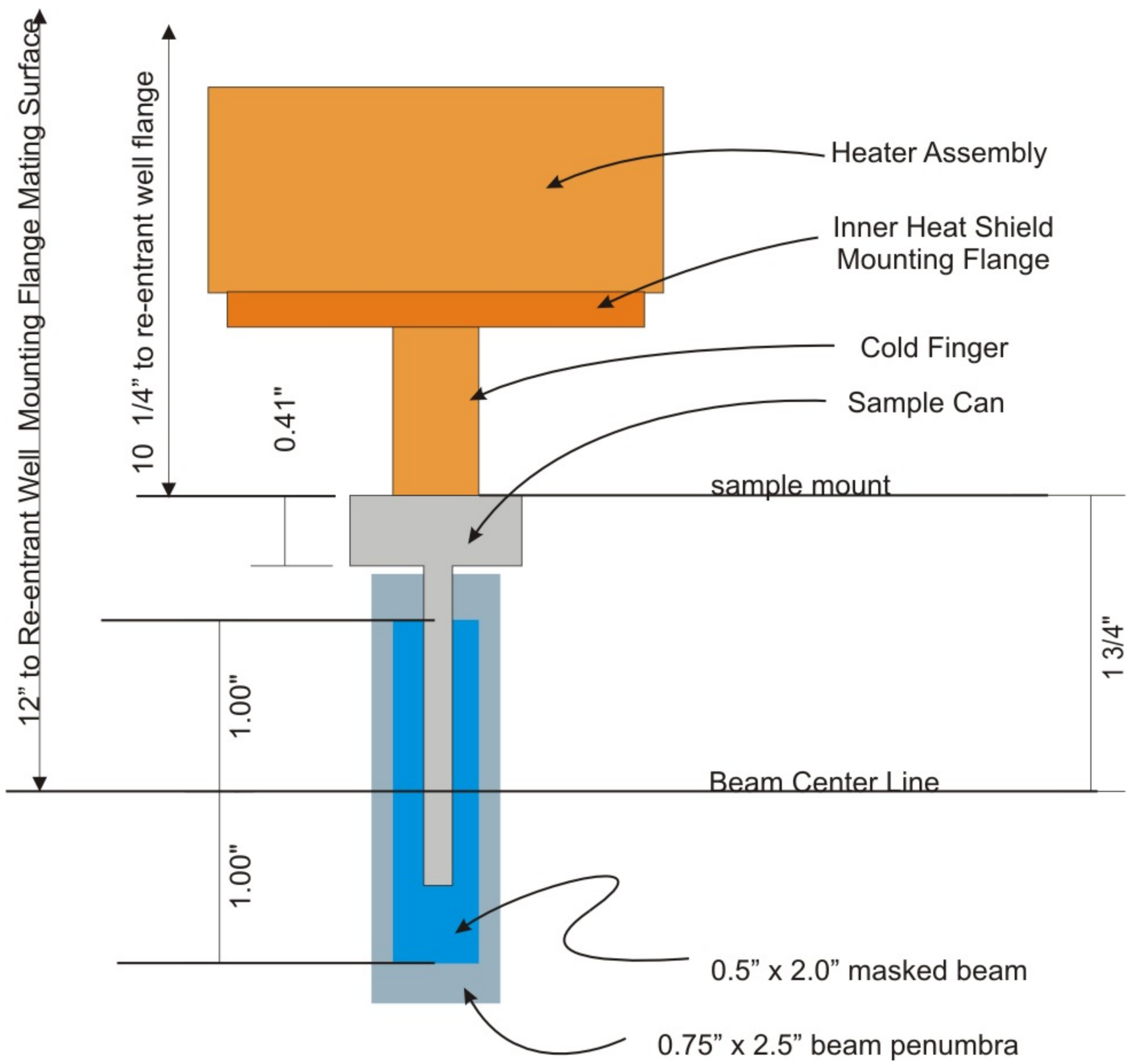

Figure 27: 1/4" can w/Al top and 0.5" x 2" mask

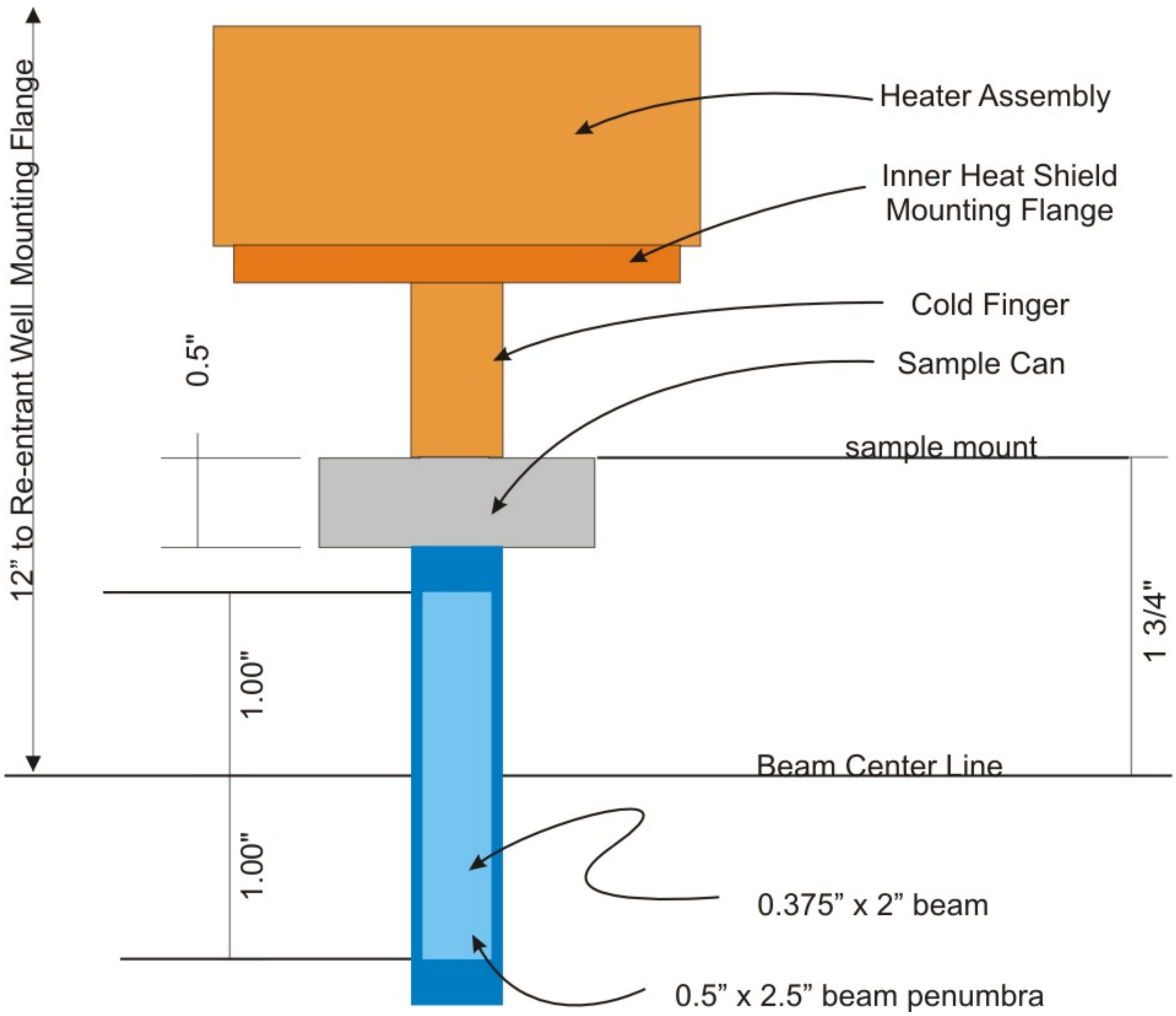

Figure 28: 3/8" NIST can w/0.375"x2" mask

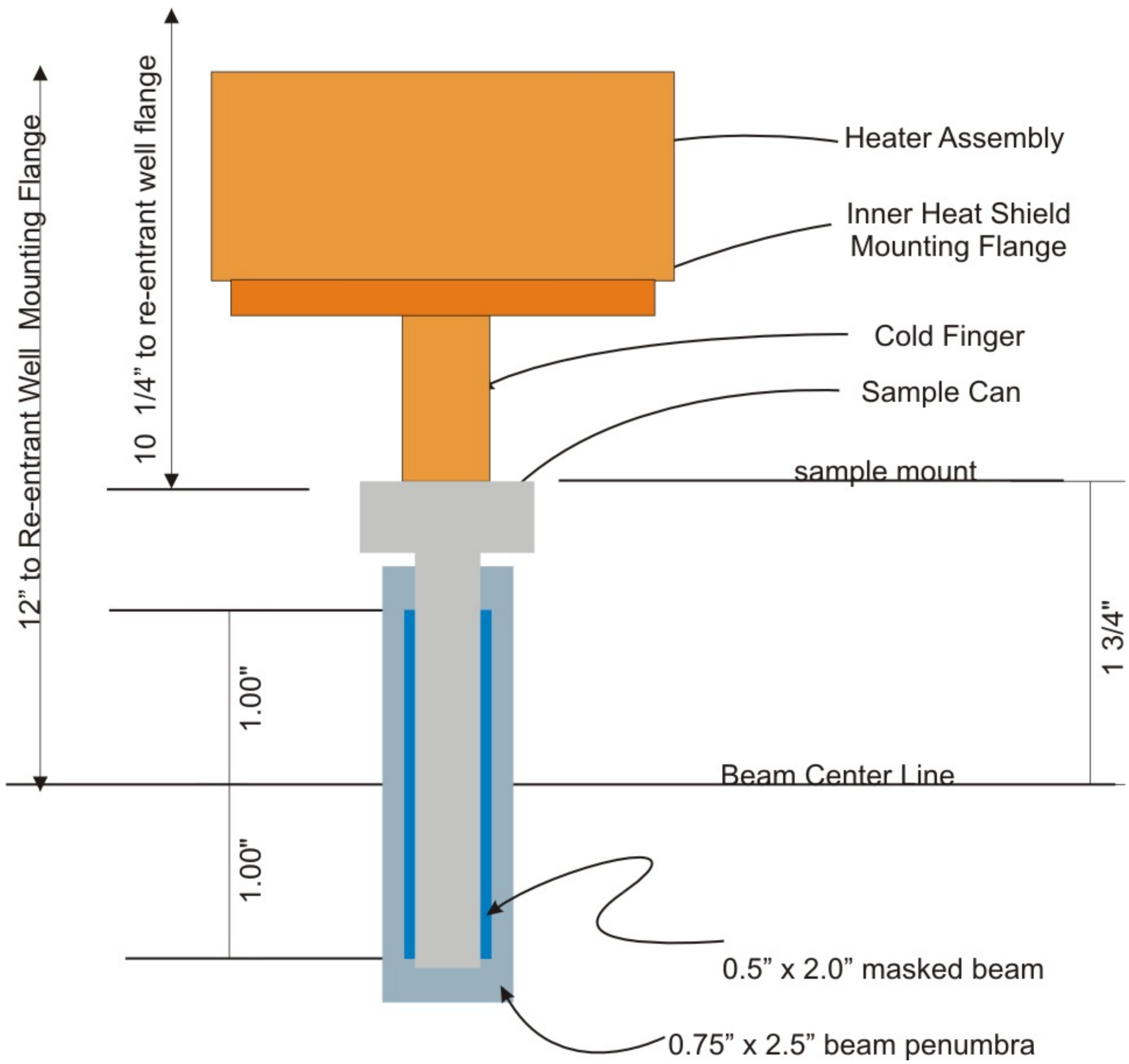

Figure 29: Medium Sized can w/ 0.5" x 2.0" mask

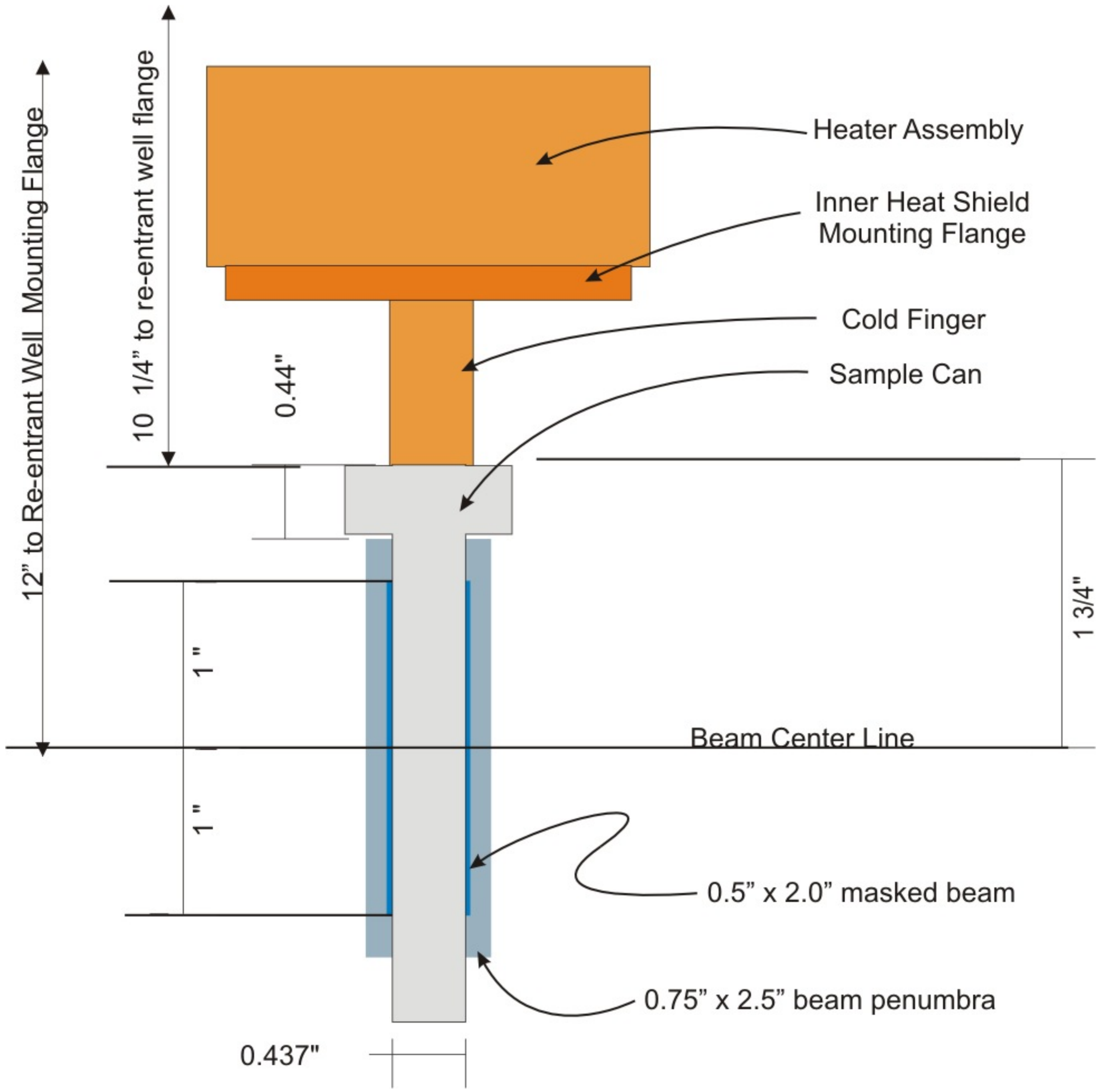

Figure 30: Large can with 0.5" x 2.0" mask

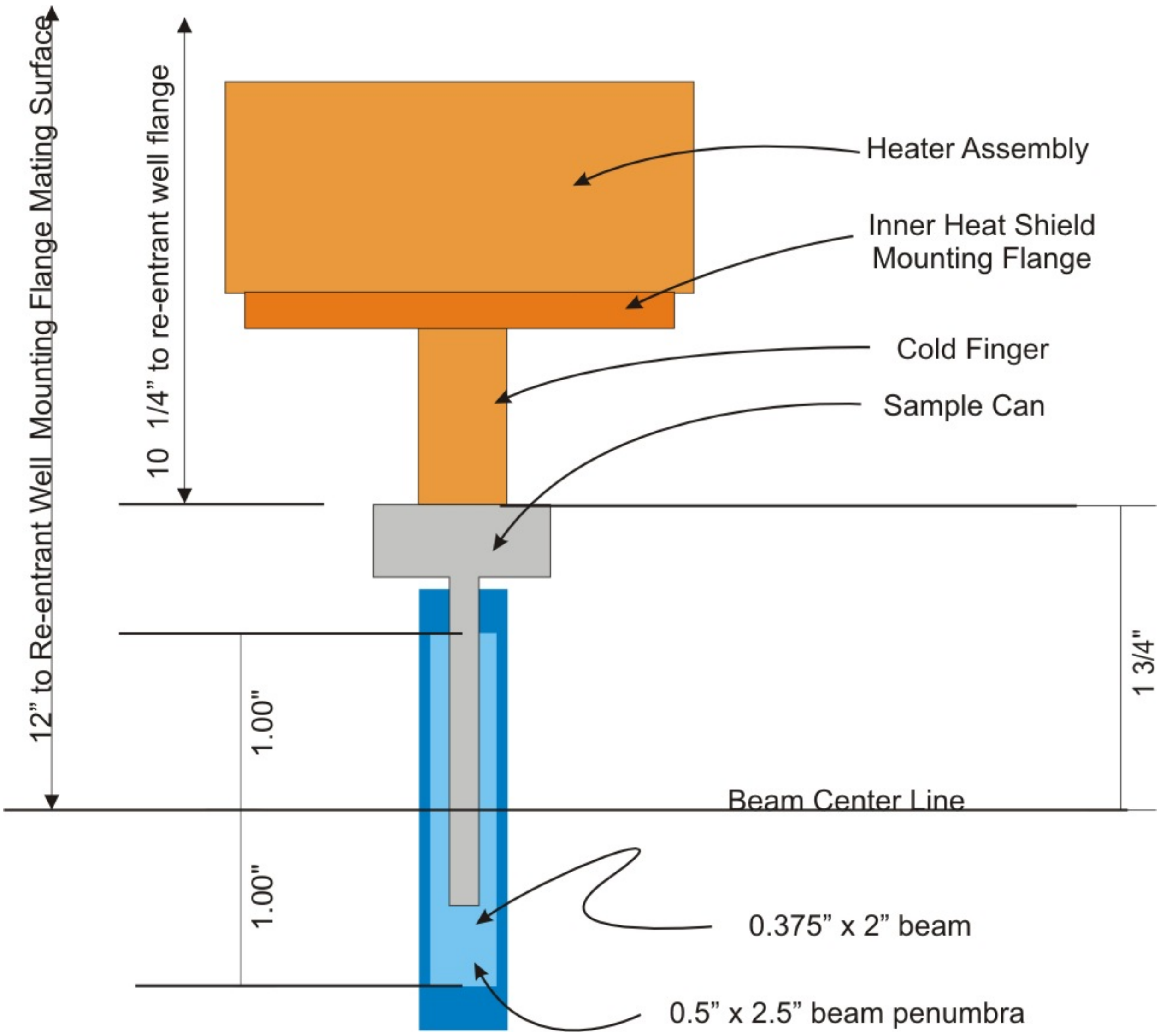

Figure 31: Small Can w/ 0.5" x 2" mask

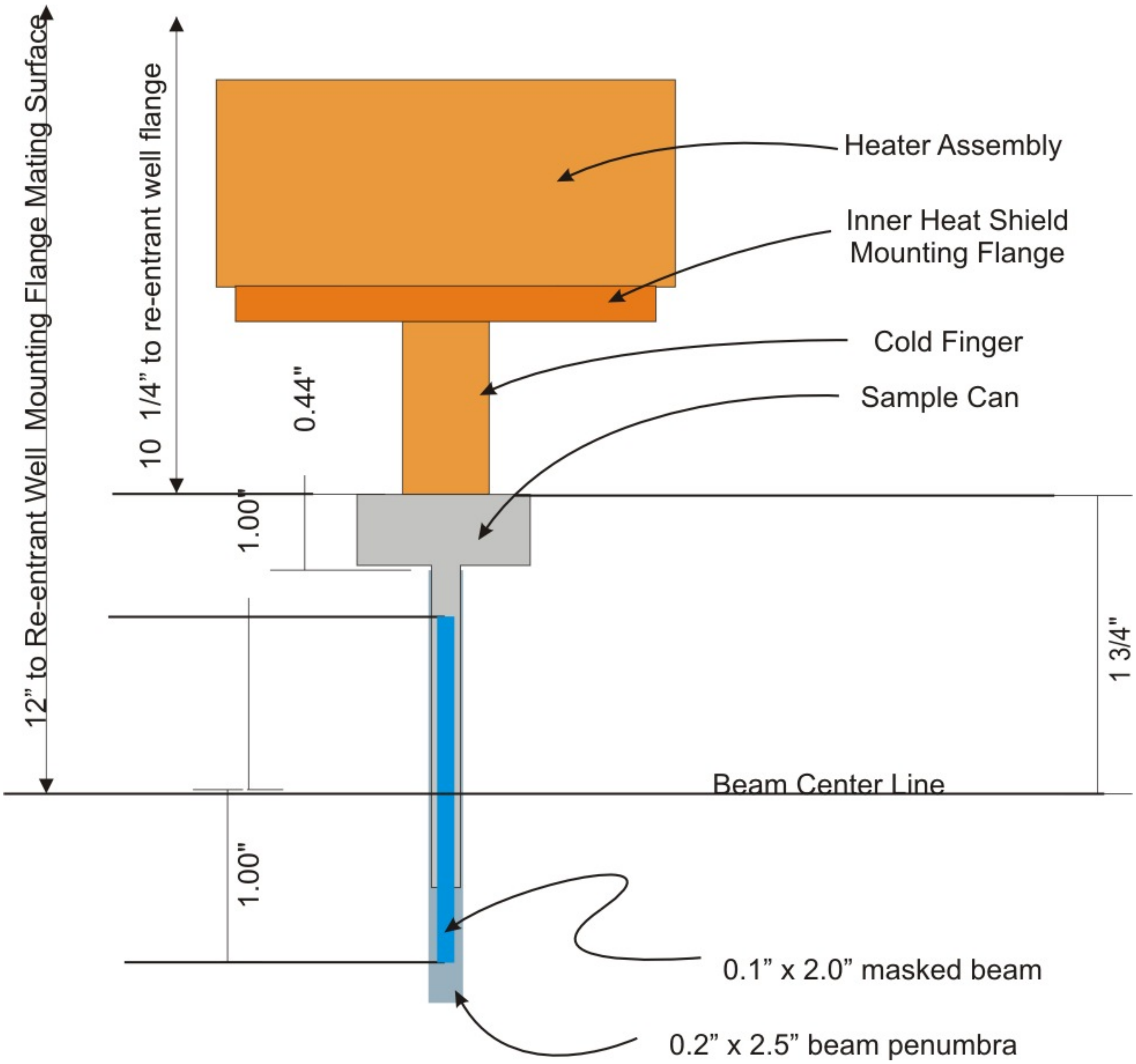

Figure 32: Small Can w/ 0.1" x 2" mask

8 Appendix C: Temperature Response

The following are the results of a “worst case scenario” study. The sample was a poor thermal conductor (Alumina Ceramic – Powder). The largest and longest vanadium can was used to keep the thermal mass high and transition times “long”.

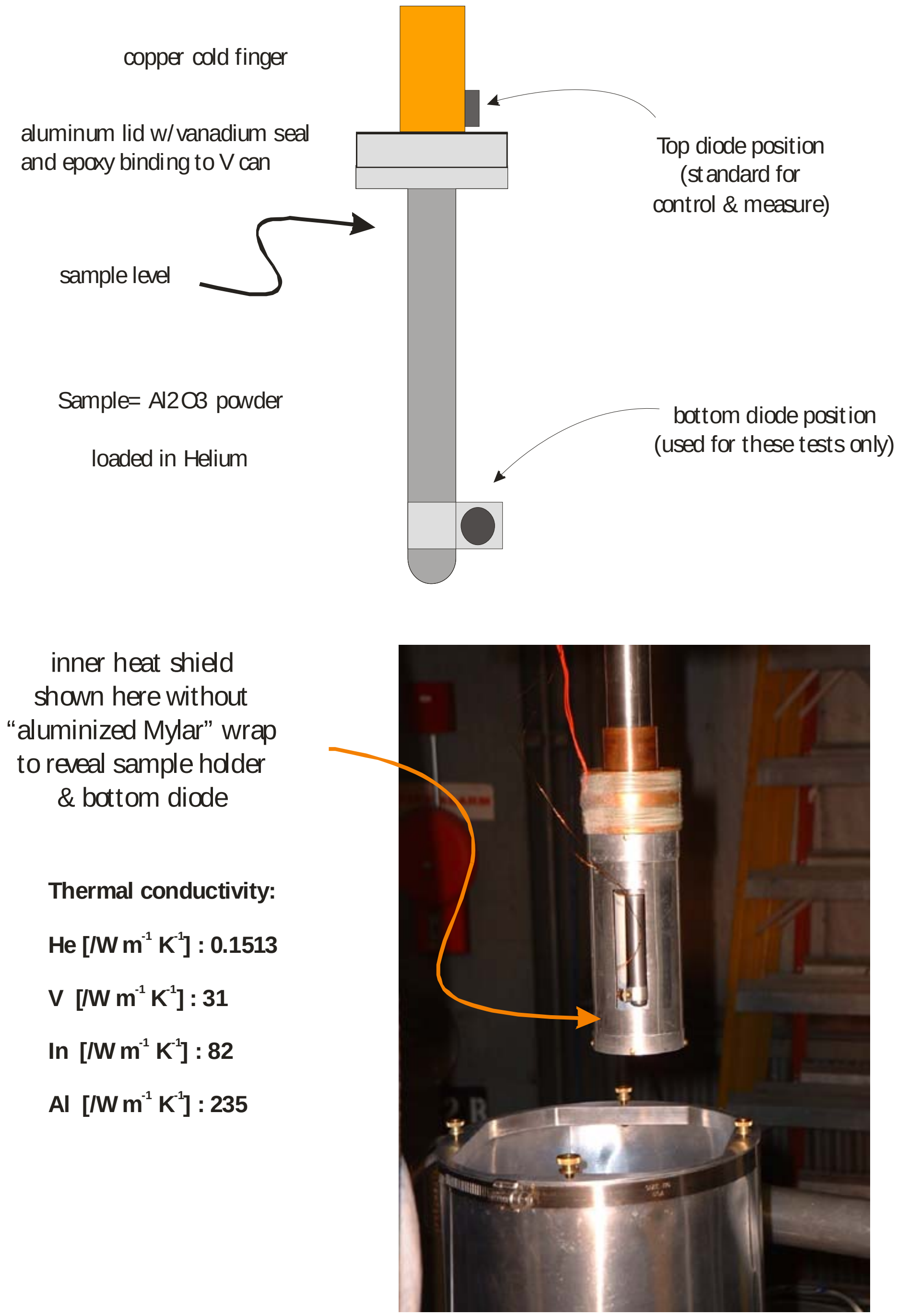

Figure 33: Temperature Response Study Scenario

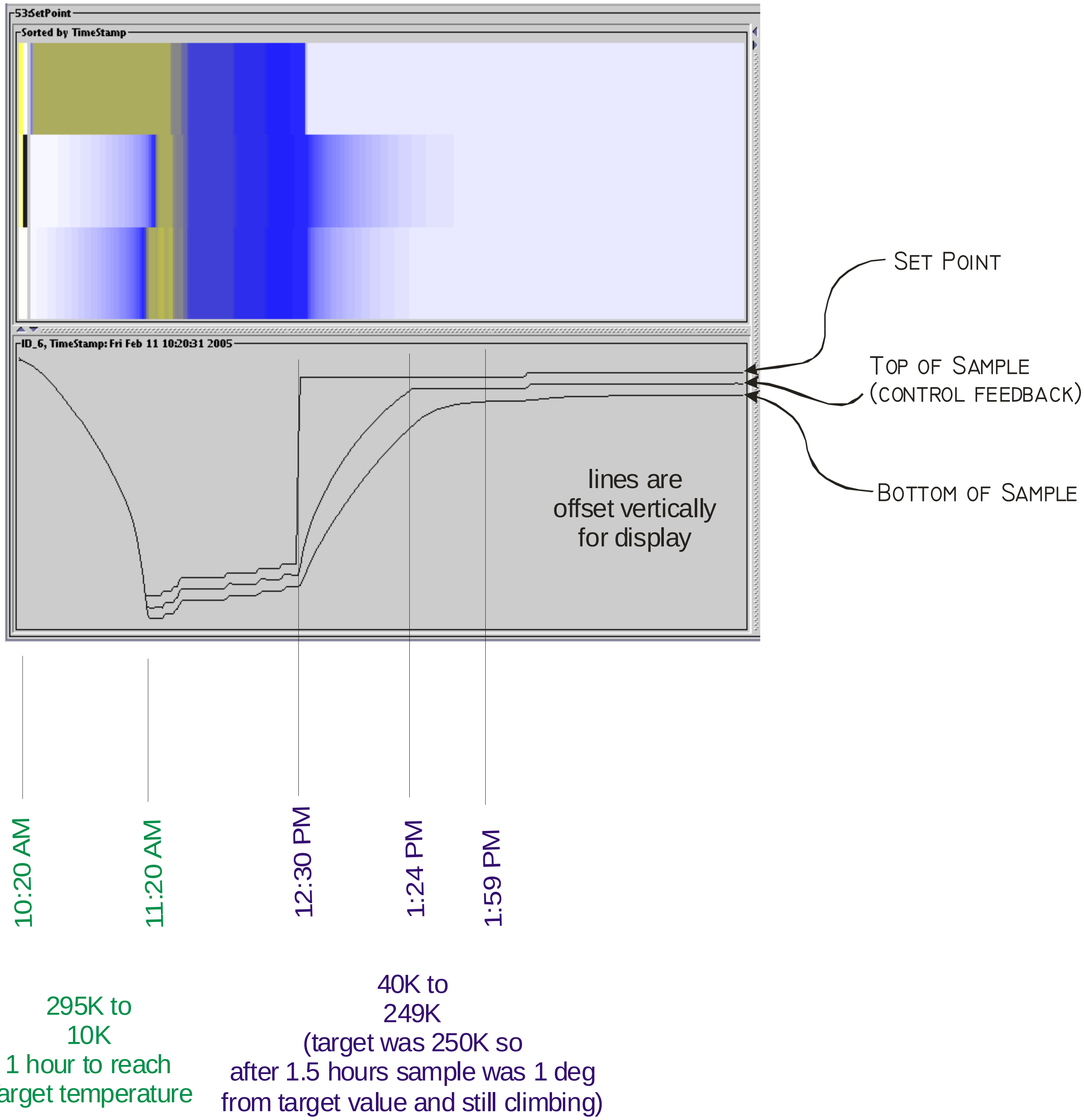

Figure 34: Large Temperature Transitions

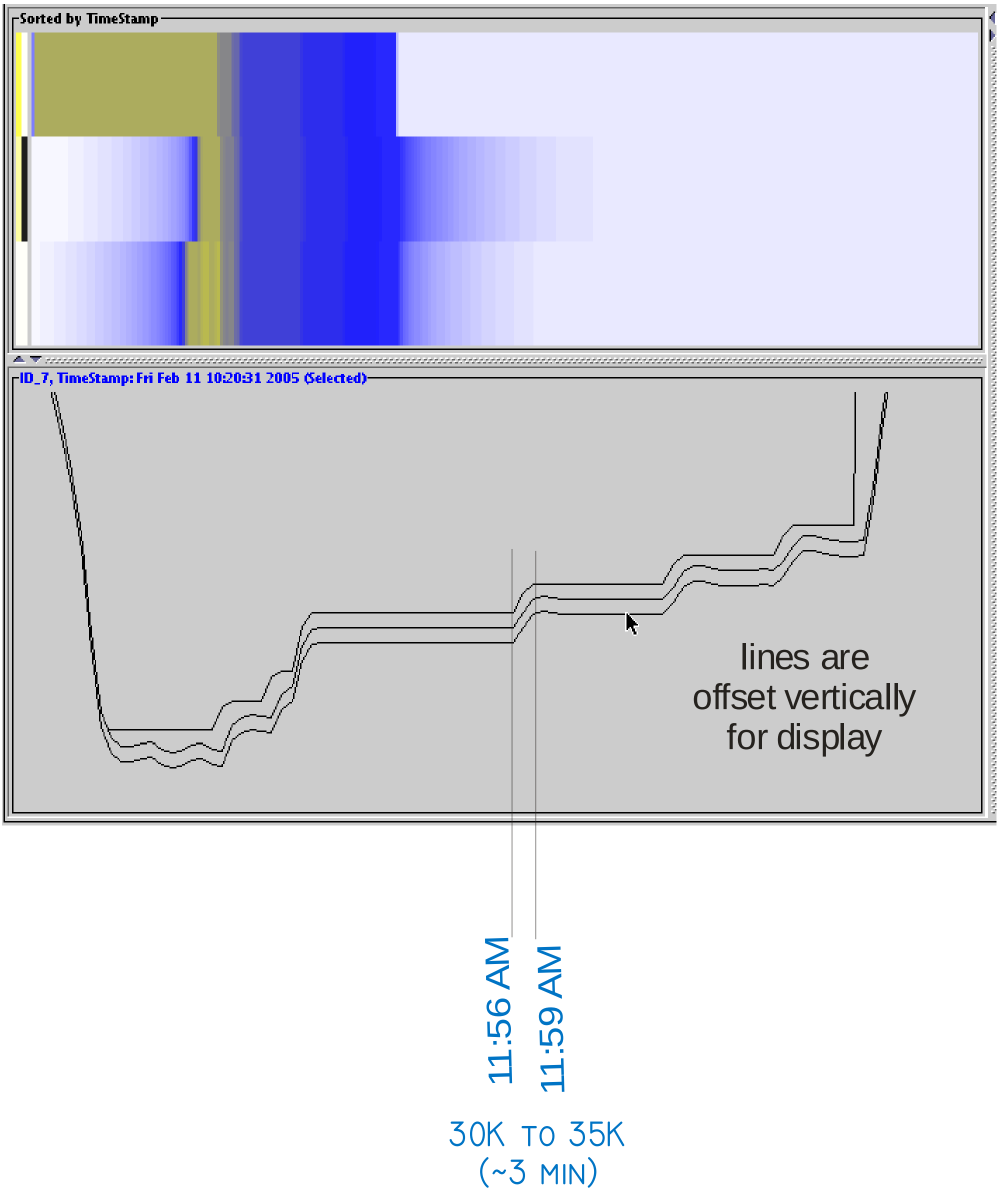

Figure 35: Small Temperature Transitions